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Influence of zinc on germination of maize (*Zea mays*) germplasm under saline stress condition

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ABSTRACT

The present study is an experimental investigation of the effects of varying rates of zinc application on maize germplasm under salt stress conditions. The experiment was conducted at Arid University Rawalpindi, using 30 standardized pots filled with a mixture of soil and sand. The pots were divided into five treatments, with zinc applied at varying rates of 0, 4, 8, 12 and 16g per pot and 16g of NaCl salt added to induce salt stress. The experiment lasted for a total of 35 days in order to examine the effects of varying rates of zinc application on various germination parameters such as germination percentage, plant height, mortal plant, shoot moisture content percentage and root moisture content percentage under salt stress. Data collection was performed by using Microsoft Excel 2016 and subjected to statistical analysis of variance (ANOVA). The least significant difference (LSD) method was employed to determine significant differences between treatment means at a 5% probability level. The results of the experiment were showed the effects of varying zinc application rates on maize germplasm germination and growth under salt stress conditions. In the experiment, various quantities of zinc (0g, 4g, 8g, 12g and 16g) were administered to plants. The treatment with 16g zinc demonstrated the highest germination percentage (100%) and the tallest plants (41.667 cm). The no zinc treatment showed the lowest germination percentage (60%) and shortest plants (22 cm). The findings indicate that zinc has a beneficial effect on plant growth and survival.

Keywords: Arid zone, NaCl, Germplasm, Saline stress, Zinc, *Zea mays*

1. INTRODUCTION

Maize (*Zea mays* L.), also known as corn, belongs to the Poaceae family and maize is a widely cultivated cereal crop in Pakistan, following wheat and rice, owing to its high production area and nutritional value. Its origin dates back to about 7000 years ago in central Mexico, where Native Americans transformed the wild grass into a better source of food. Maize is rich in macronutrients, containing about 72% starch, 10% protein and 4% fat, providing an energy density of 365 Kcal/100 g, higher than that of rice and wheat. It also contains essential vitamins, minerals and fiber. The top three maize-producing countries in the world are the United

States, China and Brazil, accounting for about 563 million metric tons/year out of the total 717 million metric tons/year worldwide (Ranum et al., 2014). Maize is a leading cereal crop globally, surpassing any other cereal grain in terms of total production (FAO, 2011). In different countries, the extraction rate for maize varies from 60% to 100% depending on the desired product. For yellow maize goods, the extraction rate ranges from 60% to 65% in the United States, whereas other countries exhibit higher extraction rates. For instance, South Africa's extraction rates for super, sifted, maize are 62%, 79-89% and 99%, respectively (National Chamber of Milling, 2008). Corn is a prominent cereal crop that is cultivated worldwide for various applications, such as human consumption, animal feed and fuel production. Industrial processing techniques are employed globally to produce refined maize flour, dehydrated nixtamalized flour, fermented maize flours and other maize products. Maize, also known as corn, is a domesticated grass that has been widely disseminated across the globe after the European discovery of the Americas. Despite its diverse origins, corn has demonstrated remarkable adaptability as a crop (Gwirtz and Garcia-Casal, 2014). Maize is a significant cereal crop, playing a vital role in human, poultry and livestock nutrition (Nuss and Tanumihardjo, 2010). Therefore, elevating the concentration of Zinc (Zn) in maize grains could potentially enhance the bioavailability of Zn to populations consuming maize-based foods directly or indirectly.

Zinc (Zn) is an essential micronutrient required for proper growth and development of crops. Its inadequacy is particularly prevalent in high-pH soils. Zinc plays a pivotal role as a constituent of various proteins in plants, although its excessive levels can be toxic. This review article aims to elaborate on the key pathways involved in Zn transportation across the soil-root-shoot continuum, including Zn inputs to soils, the solubility of Zn^{2+} at the root surface and the uptake and accumulation of Zn in plants. A thorough comprehension of these pathways can facilitate the formulation of strategies to enhance crop growth under Zn-limiting conditions. Furthermore, exploiting the significant genetic variation in Zn composition within-species offers a promising approach to address human dietary Zn deficiencies through bio fortification (Broadley et al., 2007).

Drought stress can negatively impact on growth and development of plants by altering various physiological and biochemical processes, ultimately resulting in reduced crop productivity. Zinc (Zn) is an essential micronutrient that plays a crucial role in regulating various physiological and molecular mechanisms, which can enhance crop resistance against drought stress. Recent research conducted by Hassan et al., (2020) has shown that the application of Zn under drought stress conditions can improve plant growth and performance parameters. These include enhanced seed germination, improved plant water relations, increased cell membrane stability, promotion of osmolyte accumulation, regulation of stomatal aperture, increased water use efficiency and enhanced photosynthesis. The cell membrane is widely acknowledged as the primary site of abiotic stress response, as stated by Hera et al., (2018). Maintaining membrane integrity under water stress conditions is crucial for determining the drought tolerance of plants, as noted by Bajji et al., (2002). In this regard, the supply of zinc (Zn) plays a crucial role in preserving membrane permeability, antioxidant activity, photosynthetic efficiency and water use efficiency (WUE) in plants subjected to drought stress. This assertion is supported by several studies, including (Karam et al., 2007; Bagci et al., 2007; Babaeian et al., 2011). Seed germination is a critical stage in the plant life cycle that is highly influenced by drought stress. Seedling emergence is a vital factor that affects plant density and final productivity, which makes it crucial for effective crop management. The interaction between internal seed mechanisms and environmental factors determines the degree of germination and emergence under specific conditions, according to Sedghi et al., (2013). Therefore, the role of environmental factors in seedling emergence variability is of significant importance. Several studies have shown that the application of Zn through seed priming enhances the germination and yield of crops, including maize, wheat and chickpea, even under a wide range of environmental conditions. Harris et al., (2005) and Harris et al., (2007) reported these findings.

Zinc is a vital micronutrient for living organisms, playing a significant role in the performance of various enzymes. This element acts as a regulator of phytohormones and chlorophyll synthesis and is essential for plant carbohydrate metabolism. In addition, the application of zinc can stimulate the accumulation of compatible solutes, including proline and glycine betaine, which are critical for maintaining cell turgor and protecting cellular structures against damage caused by environmental stresses. Several studies have suggested that zinc application can enhance the tolerance of maize crops to various abiotic stresses, thereby improving crop productivity (Saleem et al., 2022; Sarkhosh et al., 2022).

The current study aims to investigate the impact of varied zinc application rates on maize germplasm germination and growth under salt stress conditions. The experiment was conducted to evaluate the multiple germination components such as germination percentage, plant height, mortal plant, shoot and root moisture content %age during the 2022 cropping season. The study lasted for a period of 35 days to investigate the impact of zinc on the germination stage of plants under conditions of salt stress. The focus was on analyzing the germination parameters, as this process serves as a foundation for plant growth and biomass accumulation.

2. MATERIALS AND METHODS

The present investigation constitutes a controlled experiment carried out at Arid University Rawalpindi, positioned at geographical coordinates of Latitude 32°17'48 N and Longitude 72°21'9 E. Completely randomized design was employed with three replications. Maize was the focal crop in the study with particular attention to the Pop-1 variety. The study spanned 35 days, during which the aim was to examine the effects of zinc on the germination stage of plants exposed to salt stress. The germination parameters were examined as they form the basis of plant growth and biomass accumulation. The experiment employed 30 pots, each with a height of 30 cm, top diameter of 33 cm and base diameter of 25 cm. The pots filled with a standardized mixture consisting of 6 kg soil and 2 kg sand. The study was involved five treatments, each replicated three. Each replication had two pots and all pots randomized to ensure accuracy and validity of the results. In order to induce salt stress, a total of 16g of NaCl salt added to each pot. This amount divided into two parts, with the first 8g being applied at the time of sowing and the remaining 8g being added after complete germination. Zinc was also applied to the pots at varying rates of 0, 4, 8, 12 and 16g per pot to assess its efficacy under salt stress conditions. The purpose of this experimental design was to investigate the effects of different rates of zinc application in the presence of salt stress. The seeds selected based on their uniformity and quality, with 5 seeds sown per pot. The plants irrigated twice a week using 200 ml of water per pot, with water having a pH of 6.5 to 7.5 and an electrical conductivity of less than 1.5 dS/m. The objective of the experiment is to investigate the effects of varying zinc application rates on maize germplasm germination and growth under salt stress. The experiment evaluated various germination components such as germination percentage, plant height and mortal plant, shoot and root moisture content %age in the 2022 cropping season. Zinc was applied to the maize germplasm in the form of a soluble fertilizer, with T1 being the control group without any zinc application and T2 to T5 receiving varying doses of zinc (4g, 8g, 12g and 16g, respectively) at the beginning of the experiment.

Data analysis

Data collection and recording were performed using Microsoft Excel 2016. The collected data were then subjected to statistical analysis of variance (ANOVA) using Statistic version 8.1. Different formulas were used to examine the various parameters under analysis. To determine significant differences between treatment means, the least significant difference (LSD) method was employed at a 5% probability level, based on the work of Steele and Torrie (1980). This way allows for the evaluation of multiple means and enables the arrangement of statistically significant differences between treatments. The use of the LSD method ensures that any observed differences between treatment groups are not due to probability, but are indeed statistically significant. The present experiment aims to evaluate various germination components, including germination percentage, plant height and mortal plant, shoot moisture content percentage and root moisture content percentage.

The data for these parameters was calculated using the following formulas: The current investigation utilized several quantitative metrics to assess the growth and development of the plants. One such measure was the germination percentage (GP %), which was calculated by dividing the number of germinated seeds by the total number of seeds sown and multiplying the result by 100. The mortality percentage (MP %) was also calculated by dividing the number of dead plants by the number of germinated plants and multiplying the result by 100. To determine the plant height (PH), three random plants were selected and their height was measured using a meter rod. The shoot moisture content percentage (SMC %) was obtained by subtracting the dry weight of the shoot from its fresh weight and dividing the result by the dry weight of the shoot and then multiplying the result by 100. Similarly, the root moisture content percentage (RMC %) was calculated by subtracting the dry weight of the root from its fresh weight and dividing the result by the dry weight of the root and then multiplying the result by 100. These quantitative measures were used to obtain precise and objective data on the growth and development of the plants, which can be used to draw valid conclusions and make informed decisions about the experiment.

3. RESULTS AND DISCUSSION

The results of the experiment showed that varying levels of zinc application had a significant effect on maize germplasm growth and development under salt stress conditions. Table 2 shown, the highest germination percentage (95%) was observed in the T5 treatment group, which received the highest dose of zinc (16g). Similarly, T5 also recorded the highest shoot and root moisture content percentage (71% and 68%, respectively), while T1 had the lowest values (37% and 32%, respectively). Overall, the results suggest that zinc application can improve maize germplasm tolerance to salt stress and promote better growth and development under challenging environmental conditions.

Table 1 Different treatments and doses of Zinc and salt

Treatments	Zn (g pot ⁻¹)	NaCl (g pot ⁻¹)
T ₁	No zinc	16
T ₂	4	16
T ₃	8	16
T ₄	12	16
T ₅	16	16

Table 2 Mean Table of different parameters

Treatments	Germination %age	Mortal plant or seed %age	Plant height (cm)	Shoot moisture content %age	Root moisture content %age
T ₅ (Zn 16g)	100.00 a	6.667 c	41.667 a	91.000 a	88.667 a
T ₄ (Zn 12g)	93.33 a	20.00 bc	36.333 b	80.667 b	77.667 b
T ₃ (Zn 8g)	86.67 b	26.66 ab	31.333 c	70.333 c	67.000 c
T ₂ (Zn 4g)	73.33 bc	46.66 ab	26.667 d	63.000 d	58.667 d
T ₁ (Zn 0g)	60.00 c	60.00 a	22.000 e	53.333 e	48.333 e

Germination Percentage

The current investigation has shown that the application of zinc spray has a significant effect on the germination percentage of maize seedlings. The group treated with the highest concentration of zinc (T₅), at 100.00%, demonstrated the highest germination percentage. In contrast, the control group (T₁), which received no zinc treatment, exhibited the lowest germination percentage at 60.00% (Table 2). These findings support the potential of zinc spraying as an effective agricultural practice for improving germination rates. This study's results are consistent with those of Imran et al., (2021), found that zinc seed priming improved germination in spinach at low temperatures. Additionally, Rashid et al., (2019) investigated the effect of zinc-biofortified seeds on the grain yield of wheat and rice and found similar results to our study, demonstrating that zinc improved germination. Chen et al., (2023) conducted a research study which revealed that the application of micronutrients as a seed coating improves multiple germination parameters in crops. These parameters include mortality rate and speed of germination. Similarly, Farooq et al., (2009) found that treating seeds with zinc sulphate solutions before sowing can improve germination rates and increase plant tolerance to abiotic stress.

Mortality Percentage

This study, investigated the effect of different doses of zinc application on the mortality percentage of maize plants. The results showed (Table 2) that increasing doses of zinc application led to a decline in the mortality percentage of maize plants. The control group (T₁) had the highest mortality percentage (60.00%), while the group treated with the highest concentration of zinc (T₅) exhibited the lowest mortality percentage (6.67%). These findings indicate that zinc application can effectively reduce the mortality percentage of maize plants, which can promote an increase in crop yield. Furthermore, our results suggest that the effect of zinc on reducing plant mortality is dose-dependent. Higher concentrations of zinc provide greater benefits in reducing mortality rate. These results are consistent with previous studies that have demonstrated the positive impact of zinc on plant survival rates. For example, Chen et al., (2023) found that coating maize seeds with micronutrients significantly increased germination and reduced mortality rate. Similarly, Silva et al., (2022) reported that zinc application can reduce the impact of biotic and abiotic stress and enhance germination, leading to a reduction in mortality rate.

Plant Height

In this experimental study, the impact of various doses of zinc application on the growth of maize plants was investigated, with plant height being a crucial morphological parameter for evaluating plant development. The results of the investigation, as presented in Table 2, reveal a statistically significant and positive correlation between increasing doses of zinc application and plant

height. Notably, the maize plants treated with the highest zinc concentration (T5) displayed the tallest plant height, measuring 41.667 cm, while the control group (T1) exhibited the shortest plant height, measuring 22.000 cm. The current study findings align well with existing literature by Mohsin et al., (2014), which highlight the positive influence of zinc concentration on plant growth. Specifically, the authors observed that an elevated concentration of zinc can enhance biomass accumulation, grain yield, cob diameter and length, ultimately contributing to improved plant growth and height. According to Saboor et al., (2021), the application of varying concentrations of zinc in the presence of arbuscular mycorrhizal fungi (AM) and absence of AM fungi (NM) had a significant impact on the height of maize plants. The addition of zinc was found to be associated with an increase in plant height, as observed by the researchers. These findings are consistent with the results of the current study.

Shoot Moisture Content

The present study examined the effect of zinc application on shoot moisture content, a crucial factor in maize plant growth and development. The results demonstrated a significant impact of zinc application on shoot moisture content, with the group treated with the highest concentration of zinc (T5) exhibiting the highest moisture content (91.000%), while the control group (T1) displayed the lowest moisture content (53.333%) results showed in (Table 2). Wang and Jin, (2007) reported in their experiment that the application of Zinc (Zn) fertilizer improves the water uptake quality of maize plants, leading to an increase in shoot moisture content. They recommended the application of Zn fertilizer to maize plants that are either irrigated or adequately watered, as Zn deficiency can result in reduced water use for plant biomass production. These findings provide scientific evidence that Zn enhances the moisture content in plants, thus supporting the validity of the experiment conducted. According to the study conducted by Sattar et al., (2022); the application of Zinc (Zn) can enhance the growth of plants under conditions of water stress, provided that an adequate amount of water is supplied to the crop. This supplementation of Zinc can lead to an increase in the water content of the plant, as evidenced by an increase in biomass, yield, grain weight and root and shoot moisture content.

Root Moisture Content

The present study investigated the effect of zinc application on root moisture content, a critical parameter for determining water uptake and nutrient absorption capacity in plants. The results demonstrated a significant increase in root moisture content with increasing doses of zinc application. The group treated with the highest concentration of zinc (T5) exhibited the highest root moisture content (88.667%), while the control group (T1) displayed the lowest root moisture content (48.333%) results showed in (Table 2). These results suggest that zinc application can significantly improve the water uptake and nutrient absorption capacity of maize plants. Additionally, our outcomes are consistent with prior research that has reported the positive impact of zinc on root moisture content in different crops (Sattar et al., 2022). In their study, Zhang et al., (2020) conducted an experiment to investigate the impact of zinc (Zn) fertilizer on the grain yield (GY) and water use efficiency (WUE) of maize plants under drought stress (DS) and well-watered (WW) conditions. The researchers observed a significant increase in GY by 12.5% and 7.5% and WUE by 11% and 6.5% at Zn application rates of 50 kg ha⁻¹ under DS and 20 kg ha⁻¹ under WW, respectively, compared to the control group without Zn fertilizer. The results of the study suggest that Zn can enhance the water absorption capacity of maize plants, leading to an increase in root and shoot moisture content, and ultimately resulting in improved GY and WUE.

The graph depicts the effects of varying doses of zinc on the growth and germination of Pop-1 variety maize seedlings under salt stress conditions. The x-axis represents the different treatment groups, with T1 representing the control group that received no zinc, while T2-T5 received increasing doses of zinc. The y-axis represents the measured growth parameters; including germination percentage, mortal plant or seed percentage, plant height, shoot moisture content and root moisture content showed (Figure 1). The results indicate a (Figure 1) clear trend of increased germination percentage with increasing doses of zinc.

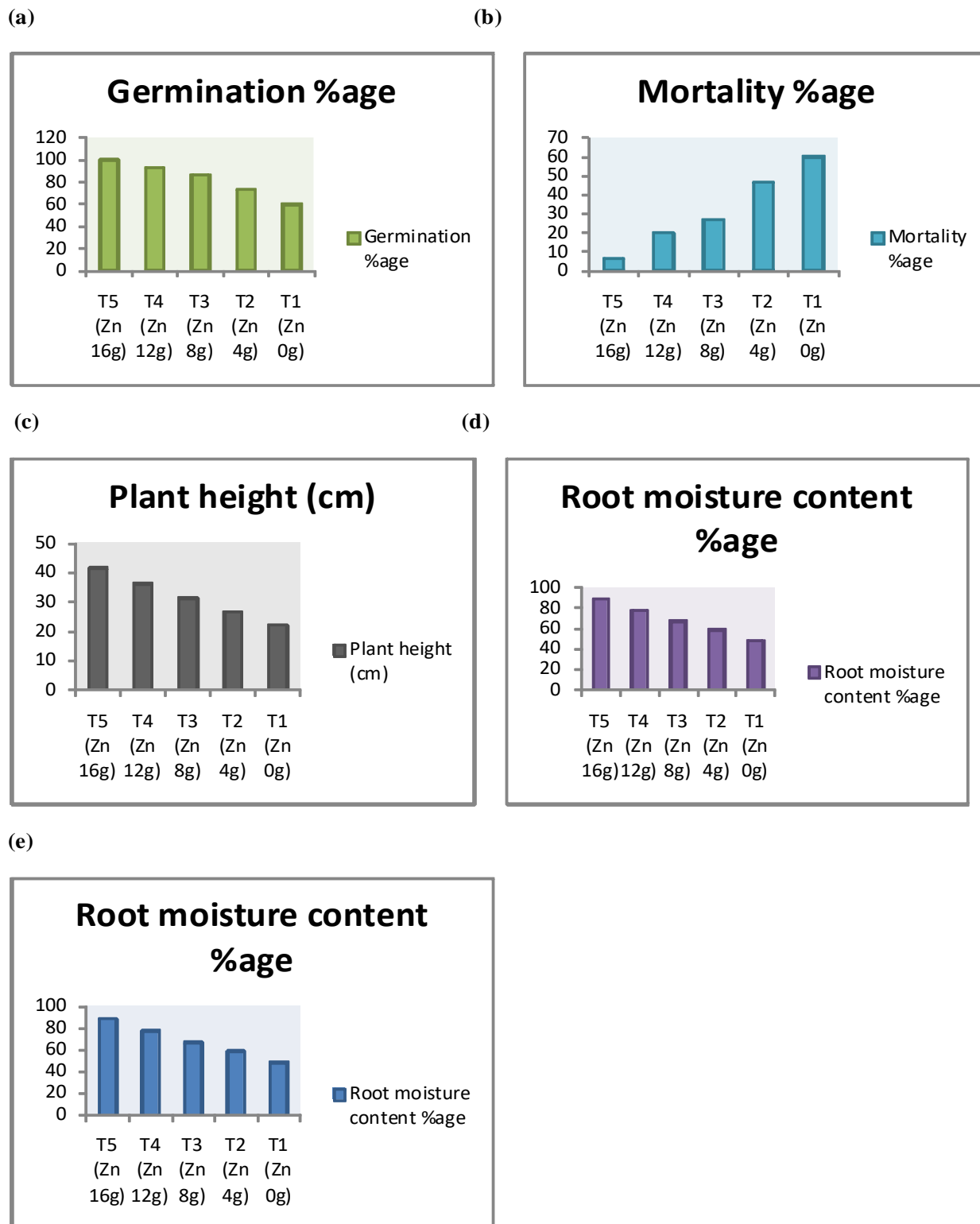


Figure 1 Effects of Zinc Dose on Germination, Mortality, Plant Height, Shoot and Root Moisture Content in Pop-1 Variety Maize Seedlings under Salt Stress

Zinc is an essential micronutrient that plays a vital role in plant growth and development. It is required for numerous enzymatic reactions, protein synthesis and hormone production, and also contributes to stress tolerance in plants. Zinc deficiency can lead to reduced plant growth, yield and quality, making it necessary to supplement zinc in agricultural soils. The previous studies mentioned in the introduction have reported similar positive effects of zinc application on various aspects of plant growth and development, including seedling germination, mortality percentage, plant height and moisture content in different crops. These

findings highlight the importance of zinc application as a valuable agricultural practice for improving crop productivity, particularly in zinc-deficient soils. The present study's outcomes provide further evidence to support these previous findings and emphasize the significance of zinc application in modern agriculture. The present study's outcomes align with previous investigations that have reported the favorable impact of zinc treatment on maize seedling germination percentage, mortality percentage, plant height, shoot moisture content and root moisture content. These findings are consistent with studies conducted by Sattar et al., (2022), Zhang et al., (2020), Hassan et al., (2020), Farooq et al., (2009), Rashid et al., (2019), Silva et al., (2022), Mohsin et al., (2014), Chen et al., (2023), Saboor et al., (2021) and Zhang et al., (2013) which have all suggested that the application of zinc has the potential to improve crop yield and growth, making it an effective agricultural practice.

5. CONCLUSION

In conclusion, the study found that varying zinc application rates had a significant effect on maize germplasm germination and growth under salt stress conditions. The results showed that zinc application at a rate of 16g produced the highest germination percentage, plant height and shoot and root moisture content, while also reducing the mortality rate of plants. These findings suggest that zinc application can improve crop tolerance to salt stress, potentially leading to increased crop productivity and sustainability in areas with high soil salinity. The study contributes to the existing literature on the role of zinc in plant growth and development and highlights the importance of considering zinc application in agricultural practices, especially in areas with challenging environmental conditions. Further studies are needed to explore the mechanisms underlying the observed effects of zinc on maize growth under salt stress condition and to optimize the application of zinc for different crop species and soil types.

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Informed consent

Not applicable.

Ethical approval

The ethical guidelines for plants & plant materials are followed in the study for sample collection & experimentation.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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The study has not received any external funding.

Data and materials availability

All data associated with this study are present in the paper.

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